INTEGRATED MANAGEMENT OF WATER RESOURCES IN WESTERN NILE DELTA

1-BUILDING AND CALIBRATING THE GROUNDWATER MODEL

A. M. El Molla[1], M. A. Dawoud[2], M. S. Hassan[3], H. A. Sayed Ahmed [3], R. F. Mohamed[4]

ABSTRACT

Western Nile delta is an important agricultural and industrial area in Egypt, in which the government has later established new reclamation projects, and irrigation and drainage networks. The increased in the reclaimed land area together with decrease in surface water discharge specially in the 1980's lead to shortage of surface water. Knowing that most of the reclaimed area lies over the Nile delta aquifer, increase in abstraction took place which might cause great damages for the ground water aquifer. The damage in the aquifer results in water level depression in most of wells, increase salinity and increase the salt water intrusion coming from the northern boundary (the Mediterranean). The objective of this study is to carry out an integrated management of water resources at Western Delta. As a first stage towards the integrated management, a complete data base for the existing discharge and water levels in the canals and drain networks is to be collected. Then a three dimensional numerical groundwater flow model should be established. The model should take into consideration the interconnection between the surface water flows in the canals and drains networks and the groundwater levels in the area. The model should simulate the Delta aquifer in order to help estimate groundwater availability and water levels in response to pumping and potential future droughts. The model was calibrated by matching observed and simulated groundwater levels for steady state condition. The model performed well in representing the water level contours of the aquifer in response to the amount of recharge from irrigation, waterways and abstraction of wells at the steady state. Sensitivity analyses for several parameters were carried out.

INTRODUCTION

Water has been the key natural-resource issue during the three millennia of recorded history in the Middle East. Egypt, although being rich in its water resources, is one of the countries faced with the possibility of chronic water shortages in the near future. Therefore, plans to increase supply or control demand should be implemented. Plans for increasing supply are difficult (but not impossible) to be implemented due to Egypt's limited water resources represented mainly by our fixed share of the Nile water, (55.5 BCM per year) . New strategies for water development and management are urgently needed to avert severe local water scarcities. Overall objective of these strategies is to utilize the available conventional and non-

1- Prof. of Civil Eng. Dept., AlAzhar University, Cairo, Egypt.
2- Researcher, Research Inst. for Groundwater, National Water Research Center, Egypt.
3- Ass. Prof., Civil Eng. Dept., AlAzhar University, Cairo, Egypt. msaadh@link.net.
4- Demonstrator, Civil Eng. Dept., AlAzhar University, Cairo, Egypt. civil_rani@yahoo.com

conventional water resources to meet the socio-economic and environmental needs of the country.

Western Nile delta is an important area in Egypt, which has limited water resources, although it lies on the western part of Nile Delta aquifer. The government established canal networks to divert surface water to this area but farmers are still suffering from shortage of surface water and are forced to depend on the groundwater abstraction from wells. Number of operating wells is increasing within the basin. Due to excess abstraction from these public and private wells (1.36 BCM during 1990), the water level in the well fields declined significantly. The decrease in the water table in the well field may lead to salt-water intrusion from the Mediterranean Sea. Farms may become covered with saline water.

To avoid the deterioration of the aquifer system in this area an efficient integrated and sustainable management plan for groundwater resources is needed. As a first stage, a complete data base should be collected and documented for the area including land levels, land use, abstraction of groundwater, main canals and drains discharge and water levels, irrigation application, aquifers system and groundwater levels. Then a model for the Nile Delta aquifer is to be built. This model should be calibrated to simulate the aquifer response in the year 1990 according to the available hydro-geologic map issued from RIGW for the Western Delta area in the year 1990. The second stage (not included in this research paper) shall make use of this model to predict for the year 2017 management scenarios as planned by the Ministry of Water Resources and Irrigation (MWRI). It should be reminded that maximum withdrawals may place a significant stress on the delta aquifer making it more expensive to pump water and forcing the abandonment of older shallow dug wells.

LITERATURE REVIEW

Several previous studies have been carried out for the aquifer systems and groundwater in Egypt.

Zaghloul, M.G., (1958), Proposed a new classification for Nile Delta aquifers. The storage possibilities in different types of aquifers are outlined. The transmitting capacity of the Delta aquifer is studied. The monthly discharges are computed at various zones and a balance is made for gains and losses.

Farid, M.S.M., (1980), Discussed a detailed description of the geological conditions of the Nile Delta aquifer. The hydrogeological and hydrological characteristics of the Nile Delta aquifer were determined. A sea water intrusion phenomenon was discussed and the study concluded that the salinity of groundwater increases northward reflecting the effect of sea water on groundwater. The sea water wedge was described suggesting sea water intrusion of about 30 km far from shoreline whereas the points of interface at distance of 80 km far from shoreline.

RIGW [Research Institute of Groundwater], (1980), Studied the groundwater aquifer in the Tenth of Ramadan City. Modeling technique was applied to determine the effect of pumping water from wells on the water levels and to estimate how much water can be pumped safely from the aquifer for a prolonged period of time.

Gomaa, O.M., (2000), studied the behavior of the transition zone in the Nile Delta aquifer under different pumping schemes. The fresh groundwater thickness increases with time, most probably due to increasing surface water diversions (especially in Western Delta and Eastern Delta regions) and also as an effect of the construction of the High Aswan Dam. The upper portion of the transition zone in the western part of the Middle Delta (till 10000 ppm line) is shifted seaside toward the north while the lower portion is shifted to the south landside. The most efficient scheme among many investigated schemes is fresh water withdrawal with abstraction barrier in the transition and at the coast. The idea of utilizing the scavenger well scheme in general has been examined as a tool for groundwater abstraction. It is concluded that the scavenger well is applied in case of two different groundwater qualities. A unique saline well could be used to control four or more fresh water wells at a certain distance (circle of influence).

RIGW/IWACO, (1990), studied the development and management of groundwater resources in the Western Nile Delta Region. Groundwater development scenarios are evaluated with numerical groundwater flow simulation using (TRIWACO) package. The model covers the major part of the Western Nile Delta region and the adjacent desert.

Khater, et al, (1991), Studied the impact of desert reclamation on groundwater quality. They stated that the results from the groundwater quality were found to be in agreement with the assessed distribution of groundwater vulnerability to pollution. Groundwater vulnerability, therefore, may be a useful tool in the planning procedures for groundwater development.

STUDY AREA

Western Nile Delta region is located between 29^{0} $30^{\backslash\backslash}$ to 31^{0} $00^{\backslash\backslash}$ E and 30^{0} $00^{\backslash\backslash}$ to 31^{0} $00^{\backslash\backslash}$ N. It occupies the area between Cairo at equator and Alexandria, west of Rosetta branch, and extends westward to the desert area from the west of Wadi el-Natrun up to the eastern edge of the Qattara Depression. Topographic data is available from survey maps of scale 1:100,000 for most of Nile Delta area. The elevation of the area ranges from (0.00) mean sea level in the north to (150.00) above mean sea level in the south. The existing irrigation networks in the study area consists of six main irrigation canals, namely The Rosetta branch, Rayah Behiri, Rayah Nasery, Nubaria canal, Mahmoudia canal and El Nasr canal. The climate of the study area can be classified as predominantly Mediterranean. The average temperature varies from 14^{o}c to 32^{o}c in months of July and August. The location of Western Nile Delta is shown in Figure [1].

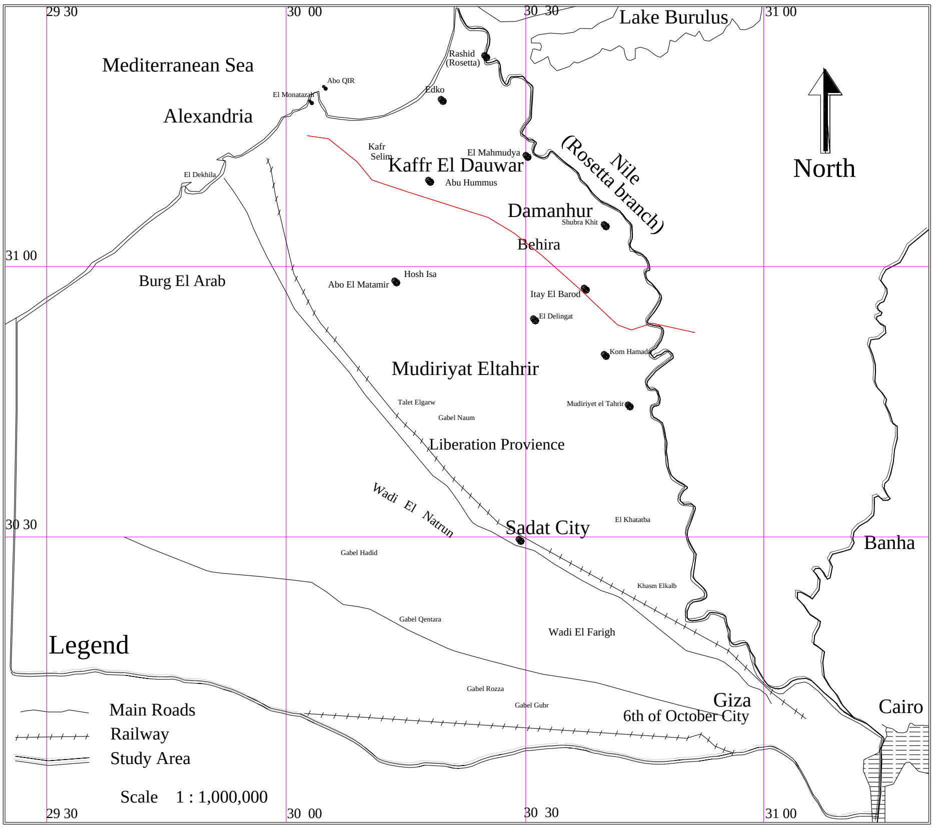


Figure [1], Domain of Study - Western Nile Delta

METHODOLOGY

The methodology is fairly straightforward and can be summarized as follows; required data for the model application were collected. This includes physical parameters such as hydraulic conductivity, aquifer thickness, recharge and pumping rates, geologic formations and layering, topographic maps, and maps with wells location and abstractions. The study area model domain was then identified. The layer has 100 rows by 100 columns, for a total of 10,000 cells. All of the cells have uniform in-plan dimensions of 1.6 km by 1.6 km. Cell size is small enough to reflect both the density of input data and the desired output detail, and large enough for the model to be manageable.

The MODFLOW program was used to simulate the three dimensional groundwater flows for the study area. The model was manually calibrated at the steady state. The steady-state model was used to investigate recharge rates, hydraulic properties, boundary conditions, flow budget, and sensitivity of the different model parameters on model results.

HYDROLOGY

Western Nile Delta region is distinguished into two main aquifers, Nile Delta aquifer and Moghra aquifer. Nile Delta is the main aquifer east of the line Abu Rawash - Khatatba - Sadat City - Alexandria. The thickness of the aquifer is 500m near Tanta, and decreases in westward direction. The aquifer is semi-confined in the Delta area, being overlain by a Holocene layer of sandy clay and silt, and in the area of Nubaria, where aquifer is covered by loamy deposits. In the rest of the area, the aquifer is phreatic (unconfined). Moghra aquifer is the main aquifer in the southern and western portions of the area. The aquifer is overlain by Pliocene and underlain by Oligocene basalt or shales. Both aquifers are connected with each other in a direct hydraulic contact along the stretch Khatatba-Abu Rawash (lateral) and along the stretch Sadat City-Khatatba (vertical). While in all other locations, the two-aquifer systems are separated by Pliocene deposits.

Recharge to the aquifer takes place due to three factors; infiltration of rainfall water, infiltration and downward leakage of excess surface irrigation water (originating from the river Nile) and leakage from canals and inter-aquifer flow of groundwater. Discharge also takes place in three ways, outflow into the drainage system, direct extraction, and evapo-transpiration and inter-aquifer flow of groundwater.

The groundwater extraction in the western Nile Delta increased from 1.36 bcm/year in 1990 to 1.92 bcm/year in 2000. The proposed cultivated areas will increase from 92,000 feddan to about 465,000 feddan in 2017. Over exploitation of groundwater and upcoming of salt water might occur in the near future at locations where extractions exceed the potentiality as defined in the development plans.

The piezometric head level of groundwater is generally decreasing within the Western Nile Delta from more than 15 m +MSL (above mean sea level) in Cairo to 1 m +MSL near the coast. The piezometric level decreases from south to north by an average piezometric gradient of about 0.00011. The groundwater levels are usually oscillating up and down affected by one or more of the following; Ground level, water levels in the river Nile and its distributors, method and frequency of irrigation, horizontal and vertical agricultural extensions, and groundwater extraction.

CONCEPTUAL MODEL FOR GROUNDWATER FLOW IN NILE DELTA AQUIFER

A conceptual model is the overall, qualitative understanding of groundwater flow in the aquifer. The conceptual model of the groundwater flow in the delta aquifer begins with surface water flow in the Rosetta branch which is then diverted towards the main and branch canals in the irrigation distribution system. Due to conductance of the layer underlying the water courses, water will infiltrate into the aquifer through the clay cap layer in most of the areas, or from the canal directly to the aquifer if they are in direct contact with each others (as part of Rosetta Branch). Groundwater is also recharged from excess application of irrigation, by deep percolation. The groundwater flow direction is in general following the land slopes.

The delta aquifer system is assumed to be a single unit unconfined aquifer. The aquifer hydraulic conductivity and other parameters were collected from previous studies on the Nile delta aquifer.

The main irrigation and drainage network for the western delta are shown in figure [2].

The groundwater flow is described by the partial differential equation in three- dimensions as follows:

$$\frac{\partial}{\partial x}\left(k_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_{zz}\frac{\partial h}{\partial z}\right)=S_{ss}\frac{\partial h}{\partial t}+R \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where k_{xx}, k_{yy} and k_{zz} are the hydraulic conductivity in x, y and z directions respectively, h is the groundwater head in the aquifer, S_{ss} is Specific storage, R is Source/sink term and t is the time.

MODEL APPLICATION

The code selected to model the groundwater flow in Nile delta aquifer is VMODFLOW, a finite difference groundwater flow code initially written by McDonald, M.G., and Harbaugh, A.W., (1988). The model design has one layer that corresponds to the nature of hydrogeologic features and boundaries. The layer has 100 rows and 100 columns, for a total of 10,000 cells. All of the cells have uniform in-plan dimensions of 1.6 km by 1.6 km. Cell size is small enough to reflect both the density of input data and the desired output detail, and large enough for the model to be manageable. Active and inactive cells layout used in the model are shown in Figure [3].

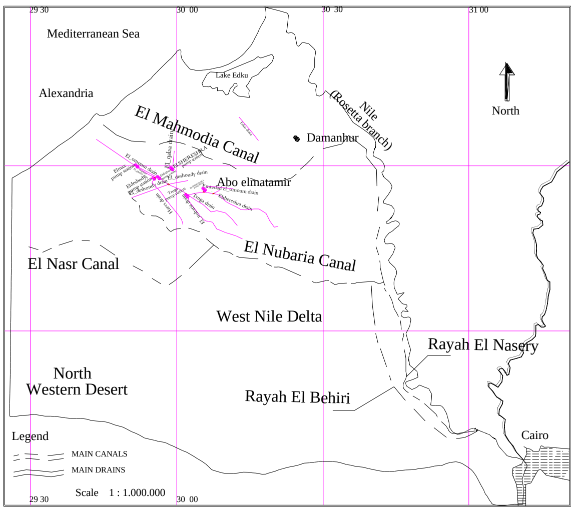


Figure [2], Main irrigation and drainage network in western delta

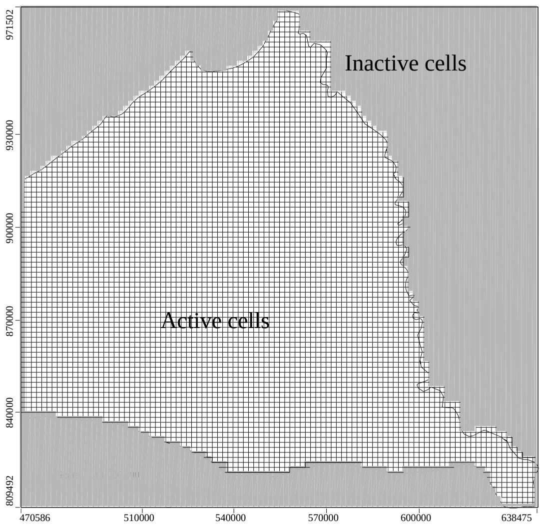


Figure [3], Cells layout used in the model

Input Parameters

The top and bottom elevation of the aquifer were defined from geographic land surface elevations and hydro-geologic maps from (RIGW, 1990). Hydraulic conductivity values were collected from several studies on the Nile delta aquifer (M.Samir Farid and Kamal Hefny, 1978 and John L. Wilson and Emad Rasmy, 1978). Different values of hydraulic conductivity K= 100, 70, 40, 30 m/day (isotropy aquifer) were used in the primary runs as shown in Figure [4]. River, canals, and drains data (flows and levels) were obtained from MWRI. Initial values of recharge were assigned according to land use and the previous studies on Nile delta aquifer (John L. Wilson and Emad Rasmy, 1978). Recharge rate was ranged from 1.5 - 2 mm/day for old agriculture area and 0.8 - 1.5 mm/day in new reclaimed areas where modern technical irrigation methods were used. Pumping from Nile delta aquifer simulated in the model as 300 well distributed all over the area. Total groundwater abstracted from the wells were 1.36 bcm/year (RIGW,1990).

Boundary and Initial Conditions

The Constant Head boundary condition was used to fix the head values in selected cells along the boundaries of the model. The constant head data were obtained from the hydrogeologic map for the Nile delta, and shown in Figure [5].

Steady-State Calibration

Calibration of flow model refers to a demonstration that the model is capable of producing results near to that measured (heads and flows). The Nile delta aquifer was calibrated using observed groundwater levels in the year (1990).

The simulated water levels generated by the calibrated model match the observed water levels quite well. The calibrated model reproduces the direction of groundwater flow and water levels in most parts of the study area to a good precession. The root mean square error was 7.5%, on average. Simulated water level differs by about 30 cm from the observed water level. Errors are generally spread across the model area. The model calibration was not unique, as it was possible to satisfy a ratio of parameter values and reproduce results with different parameter sets. Considering this fact, the qualitative evaluation, documented range for each parameter and the understanding of the conceptual model plays an important role in selecting the most appropriate set of parameters.

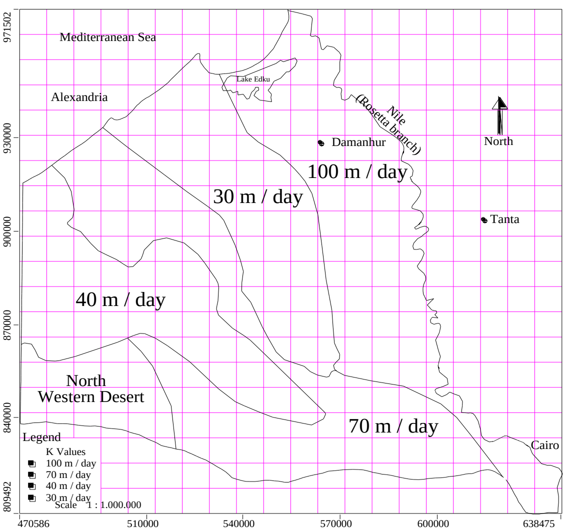


Figure [4], Distribution of hydraulic conductivity values

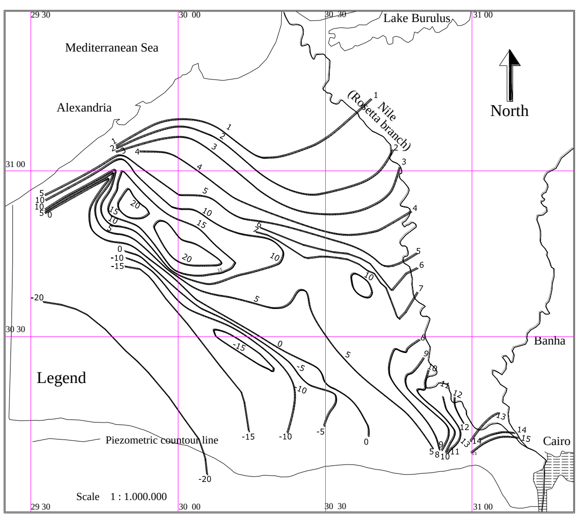


Figure [5], Constant head boundaries in Western Nile Delta (after RIGW, 1990)

Hydraulic conductivity values are one of the most difficult terms to characterize. The final values for hydraulic conductivity were not changed, during calibration, from that initially set as they provided a good match between simulated and observed heads together with the solid ground from which they were induced. Streambed conductance was increased by a factor of about three to increase the interaction between streams and the aquifers. Adjustment of river conductance and canals conductance had minimal effect on the model runs. Canals conductance adjustment had minimal impact due to the limited number of significant canals. Drains were included primarily to insure that the model could discharge water over a large area if the water level exceeded the land surface elevation. Figure 6 shows the observed versus calculated groundwater contour levels.

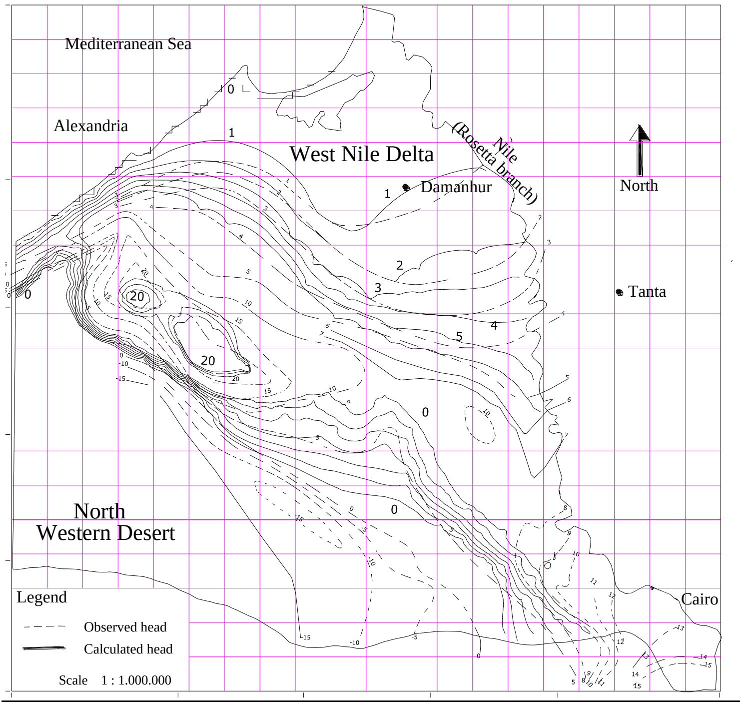


Figure [6], Observed Versus Calculated head

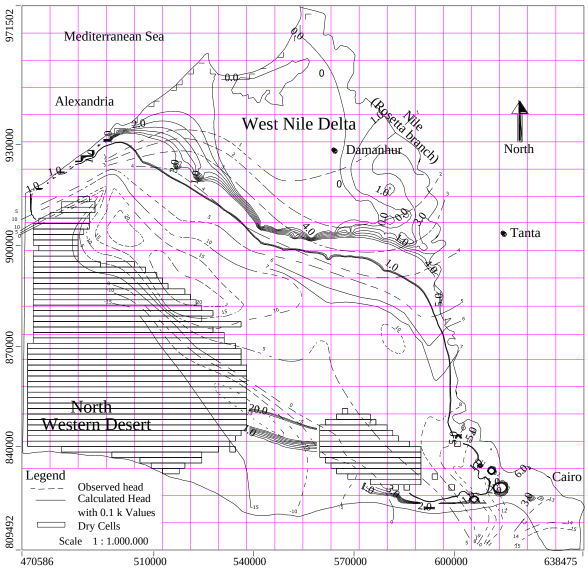
Model Stability and Sensitivity Analysis

During calibration it became apparent that the stability of the model was sensitive to the large number of cells pinching out at the up limit of each outcrop. This is expected because these cells have considerable potential for dewatering and are subject to recharge. These factors produce a system prone to solver oscillations and wetting/drying oscillations.

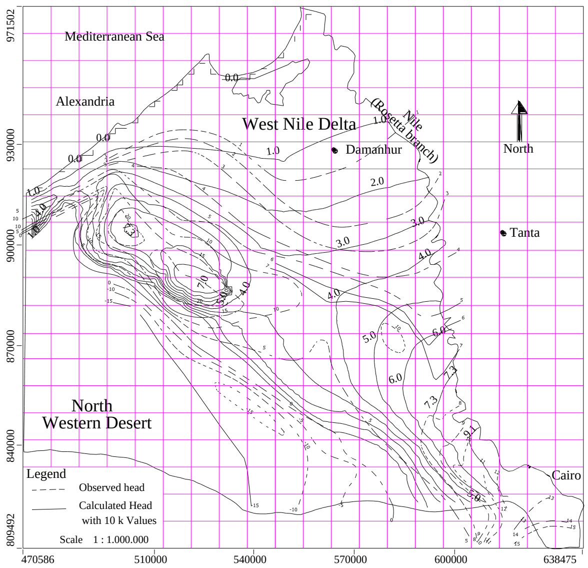
Sensitivity analysis was performed to quantify the uncertainty in the estimates of the different aquifer parameters used in the calibration of the model. During a sensitivity analysis, calibrated values of any number of parameters such as hydraulic conductivity, recharge and boundary conditions are systematically varied to observe changes in head residuals as a measure of sensitivity of the solution to each individual parameter. Sensitivity analysis, an essential step in modeling applications, also identifies hydraulic parameters that mainly control water levels, flows to springs or leakage to streams.

Sensitivity analysis was conducted on a number of parameters including recharge and hydraulic conductivity for the Nile Delta aquifer. Two runs were carried out to check the model sensitivity to hydraulic conductivity using factors (0.1, 10) from the original calibrated values of hydraulic conductivity. Piezometric head changes due to factored hydraulic conductivity are shown in Figures [7 a - b]. Sensitivity of the model due to recharge also checked by using factors (0.5, 2) from calibrated recharge values. . Piezometric head changes due to new factors of recharge are shown in Figures [8 a - b]. Sensitivity analysis performed by changing one parameter value at a time and noting the effects of the parameter change on the calibrated values.

The basic sensitivity analysis determined that the water levels in the Nile delta aquifer were sensitive (to a certain extent) to a number of parameters including horizontal and vertical hydraulic conductivity, the abstraction rate and the effective recharge rate.

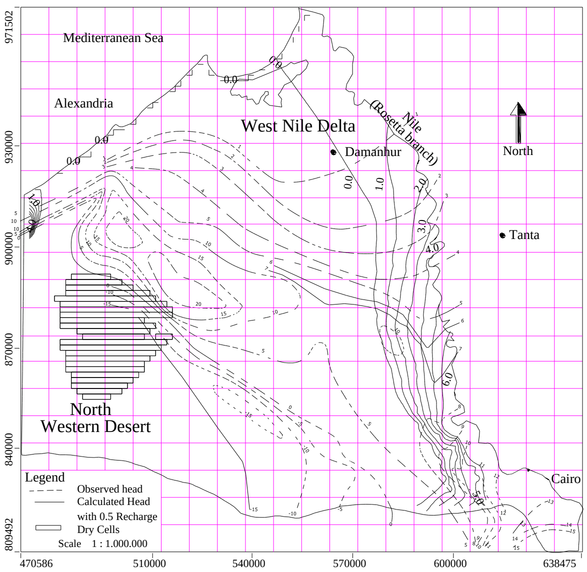


7-a

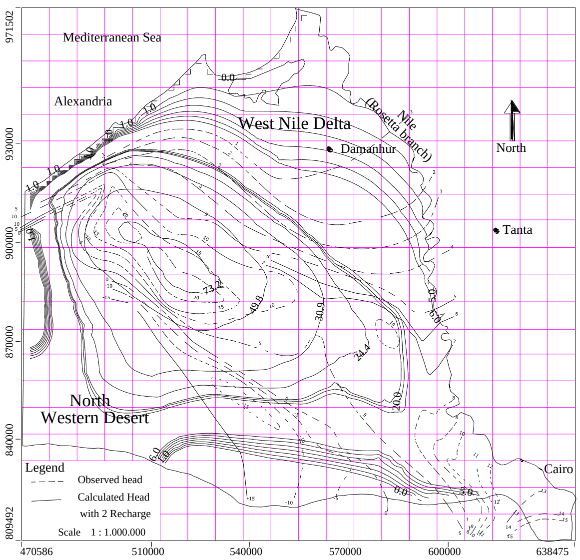


7-b

Figures [7a & b], calculated head with 0.1 and 10 times the hydraulic conductivity values respectively



8-a



8-b

Figures [8a & b], calculated head with 0.5 and 2 times the recharge values respectively

Sensitivity Analysis Results and Discussion

It can be observed that, by using one tenth of the permeability or one half of recharge is increasing the dry cells at the western part of the model and limiting the aquifer active zone to be much near to the Rosetta branch. While the values of ten times the permeability or two times the recharge widely spread the piezometric head over the modeled area. This can express how much the model is sensitive to the change in the recharge values compared with the permeability values.

SUMMARY AND CONCLUSION

- Data base and a three dimensional groundwater model was successfully built to simulate the behavior of groundwater system and its interaction with surface water at western Nile Delta area. The model was calibrated on the year 1990 levels and flows.
- Due to the direct hydraulic connection between Rossetta branch and the Nile delta aquifer, any change in the branch levels will affect the groundwater levels and the regional water balance. For most of other main water ways, the high resistance (due to the low vertical permeability of top clay layer) affects the rate of infiltration from the main canals and drains. The resulting infiltration rate from main canals and drains is small compared to that gained from Rosetta branch.
- Current unregistered abstraction from the groundwater can lead to serious damage and exploitation of the aquifer.
- The northwestern part of the study area had the highest water levels inspite of extensive water pumping and reasonable recharge amounts. The analysis indicated that this might be attributed to the small aquifer thickness and the elevated aquifer base in this area.
- The calibrated model was used to investigate mass balance of water moving through the aquifers. According to the calibrated model, the rate of flow entering the aquifer is approximately 1.54 bcm/year.
- The calibrated model was also used to investigate the influx and outflux along the model boundaries. Water budget indicated that values of in and out constant head flux along the boundaries were 0.16 and 0.3 bcm/year respectively.

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الإدارة المتكاملة للموارد المائية في غرب دلتا النيل- ١- بناء نموذج المياه الجوفية ومعايرته

تعتبر منطقة غرب دلتا النيل أحد المناطق المهمة في مصر لذا أنشأت الحكومة فيها مشروعات جديدة لاستصلاح الأراضي ، وشبكات الري والصرف. وقد أدت الزيادة في الأراضي المستصلحة جنبا إلى جنب مع انخفاض أداء شبكة القنوات وخاصة في الثمانينات إلى النقص في كميات المياه السطحية.
وقد طورت وزارة الموارد المائية والري خطة تنمية شاملة ، سوف تزيد مساحة الأراضي المستصلحة إلي ٦٢٥،٠٠٠ فدان في منطقة غرب الدلتا قبل عام ٢٠١٧.
وتهدف هذه الدراسة إلي تنفيذ الإدارة المتكاملة للموارد المائية في غرب الدلتا طبقا لهذه الخطة. ولتحقيق ذلك تم استكمال قاعدة البيانات الهيدرولوجية وإنشاء نموذج عددي ثلاثي الأبعاد لتدفق المياه الجوفية ، يأخذ بعين الاعتبار الترابط بين تدفقات المياه السطحية في شبكات الترع والمصارف ومستويات المياه الجوفية في المنطقة. وقد تم معايرة النموذج، وأظهر النموذج أداء جيدا في وتمثيلا مطابقا لمستويات المياه الجوفية في الحالة المستقرة، وتحليلات حساسية النموذج